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Update to the Propagation and Establishment of Aquatic Plants Handbook

R. Michael Smart, Gary O. Dick, and Joe R. Snow

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Environmental Laboratory

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ABSTRACT:

Man-made reservoirs initially lack aquatic plants, and their operation for flood protection or water supply may result in extreme water level fluctuations that hinder natural establishment. In many cases natural establishment could take decades or even longer. In the interim these reservoirs provide relatively poor aquatic habitat and water quality. Unvegetated aquatic ecosystems are also at risk of invasion by problematic, nonindigenous species. These unvegetated man-made systems would benefit from establishment of native aquatic plants.

Even natural ecosystems such as lakes and ponds may have lost their aquatic flora due to chronic disturbance or long-term vegetation management. These systems also often suffer impaired water quality, are at risk of re-invasion by exotic species, and would benefit from native plant restoration.

This report describes updated techniques for production of plant propagules and their use for establishment of native plant communities in unvegetated freshwater ecosystems.

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Preface

The work reported herein was conducted as part of the Aquatic Plant Control Research Program (APCRP), Work Unit 33084. The APCRP is sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE), and is assigned to the U.S. Army Engineer Research and Development Center (ERDC) under the purview of the Environmental Laboratory (EL). Funding was provided under Department of the Army Appropriation Number 96X3122, Construction General. Mr. Robert C. Gunkel, Jr., EL, was Manager, APCRP. Program Monitor during this investigation was Mr. Timothy R. Toplisek, HQUSACE.

Principal Investigator for this study was Dr. R. Michael Smart, Lewisville Aquatic Ecosystem Research Facility, Aquatic Ecology and Invasive Species Branch, Ecosystem Evaluation and Engineering Division (EEED), EL. The report was prepared by Dr. Smart and Dr. Gary Owen Dick and Mr. Joe R. Snow, both assigned to EEED under an Intergovernmental Personnel Act Agreement with the Institute of Applied Science, University of North Texas, Denton, TX. The report was reviewed by Ms. Chetta Owens, ASci Corporation, and Ms. Dwilette McFarland, EEED.

This investigation was performed under the general supervision of Dr. Elizabeth Fleming, Acting Director, EL; Dr. Dave Tazik, Chief, EEED; and Dr. Al Cofrancesco, Chief, Aquatic Ecology and Invasive Species Branch, EEED.

COL James R. Rowan, EN, was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

1 Introduction

Background

Aquatic ecosystem restoration frequently includes establishment or reestablishment of aquatic plant communities. Many reservoirs without aquatic plants suffer from poor water quality (high nutrients, poor visibility, etc.) and weak fisheries (absence of cover and nursery habitats), and are susceptible to invasions by weedy exotic plant species (Smart and Doyle 1995).

The role of plants in aquatic systems is significant. Aquatic plants provide valuable fish and wildlife habitat (Dibble et al. 1996), serve as a food source for waterfowl and other aquatic wildlife, improve water clarity and quality (James and Barko 1990), reduce rates of shoreline erosion and sediment resuspension (James and Barko 1995), and help prevent spread of nuisance exotic plants (Smart et al. 1994).

Typically, three situations occur in large, multipurpose reservoirs that qualify for restoration through establishment of native aquatic plants: (a) an absence of vegetation, (b) low species diversity, or (c) infestation by nuisance exotic plants species such as hydrilla (*Hydrilla verticillata*). In the first two situations, restoration involves addition of desirable species of aquatic plants; in the latter, it involves control of the invasive exotic species.

Aquatic plant communities in natural lakes develop over hundreds or thousands of years (Doyle and Smart 1993). The average age of 672 Corps of Engineers reservoirs is 40 years; thus, not enough time has passed for natural introduction and establishment of native aquatic plants. Time is not the only limitation: an absence of propagule sources, harsh abiotic conditions, and biotic pressures all contribute to reducing the likelihood that aquatic plants will become established in any given reservoir.

Reservoirs are often constructed in areas that lack natural lakes, and may be remote from populations of aquatic plants that could serve as propagule sources. As a result, many reservoirs have no aquatic plant seed bank and receive only limited inputs of seed and other plant propagules. These reservoirs are often first colonized by nuisance exotic weeds, frequently a result of accidental introduction by boaters. These species are adapted for exploiting disturbed conditions, and may quickly spread to become problematic (Smart and Doyle 1995). Once established, exotic weeds can prevent establishment of native plants, regardless of subsequent propagule availability.

Abiotic conditions unfavorable to plant establishment may include excessive water level fluctuations, high turbidities, and shifting sediments. Small, young plants are especially vulnerable to changing water levels that may place them in water too deep or muddy to allow for adequate light penetration or so shallow as to expose them to turbulence or desiccation or cover them with sediments (Smart and Doyle 1995).

Biotic disturbances are caused by a number of aquatic and semiaquatic organisms. Fish and other animals that feed or root in sediments easily dislodge seedlings and other small plants. In addition, turtles, crayfish, insect larvae, mammals, and waterfowl have been shown to impair establishment and/or growth of submersed aquatic plants (Lodge 1991; Dick et al. 1995; Doyle and Smart 1995; Doyle et al. 1997). Many of these grazers are omnivorous, and their presence is not dependent on prior availability of plants. Because of their mobility and widespread distribution, aquatic omnivores are often present in numbers sufficient to prevent, or at least delay, natural establishment of aquatic vegetation. Additionally, grass carp (*Ctenopharyngodon idella*) have been used to control aquatic weed infestations in some systems, and their continued presence may prevent establishment of most aquatic plant species for many years (Smart et al. 1998).

Approach

An approach has been developed for accelerating the natural process of aquatic plant establishment by overcoming one major impediment: availability of propagules. Continual provision of propagules ensures that they are present when conditions are suitable for natural establishment, greatly shortening the time required for vegetative colonization to occur. The approach utilizes *founder colonies* as propagule sources: these are small colonies of aquatic plants established in strategic locations within the reservoir. Once established, founder colonies spread in two manners, including expansion (vegetative spread from the founder colony itself) and colonization (formation of new colonies from fragments, seeds, etc.) (Smart et al. 1996, 1998).

Objective

Establishment of founder colonies faces the same impediments as natural establishment, and relies on planting of robust propagules (such as mature transplants) into protected sites (Smart et al. 1996, 1998). This handbook describes techniques for producing aquatic plant propagules and for planting these propagules in reservoirs.

Many techniques presented here have not been rigorously tested in multiple systems. While these methods have been used with some success, they may not be universally applicable due to differences among plant species, among regions of the country, and among reservoirs. Annual variations in weather and hydrology are likely to affect the outcome of any plant establishment efforts. These techniques are certainly not the only means of establishing aquatic vegetation,

and new methodologies continue to be developed and evaluated at a number of reservoirs in several southern states. Likewise, thus far the establishment of only a few species has been attempted on a large scale or in multiple situations, and the establishment of additional species continues to be evaluated. Some of these new techniques and new species will prove successful while others may not. This handbook is an update to an earlier version (Smart and Dick 1999) and incorporates experience gleaned from several years' experimental work and actual ecosystem restoration projects (Dick and Smart 2004; Dick et al. 2004a,b).

2 Propagule Production

Justification

Each restoration project requires many individuals of several aquatic plant species. Even on the scale of founder colony establishment, plant numbers required can be quite high. Because acquisition of large numbers of appropriate propagules in a timely manner can be difficult, methods have been developed for producing transplants and other propagules tailored for each specific project.

Although commercial suppliers may in the future provide propagules of all plant species needed for restoration, at present most restoration projects will require at least some in-house propagule production. Currently, only a limited selection of aquatic plant species (particularly submersed plant species) is readily available from commercial sources. Additionally, propagule types offered are seldom suited to the demands of plant establishment in large water bodies; for the most part, stem fragments, seeds, root crowns, or dormant perennating organs (tubers, winterbuds) are sold commercially. These propagules require near-ideal conditions for successful establishment, and in the authors' experiences with harsh environments of artificial reservoirs, most are destined to fail.

Another concern regarding dependence upon commercial supply is that such propagules are often available only seasonally, very possibly at the wrong time of the year for a particular restoration project. One reason for this is geographic location of commercial suppliers/collectors. As an example, northern suppliers generally must wait until spring thaws occur, which may be beyond the period for optimal establishment in southern reservoirs. In other cases, propagules may be readily available in the spring, but hydrologic conditions (e.g., spring flooding) may dictate planting at a later date. Plant material, even dormant propagules, may not survive holding for extended periods.

Species locality is also an issue of concern. Although a particular species may be found throughout the United States, it may vary genetically in different regions. Because such variations are likely due to differences in environmental (climatic or geological) conditions, a northern variety may not do well in southern climates. An example of this is seen in wild celery (*Vallisneria americana*), in which the northern form enters dormancy and produces tubers to survive winters, whereas the southern form remains evergreen and does not produce tubers. Finding source plants locally (or as locally as possible) is highly recommended.

Because finding local plant stocks and cultivating desired species are the most likely means of acquiring suitable plants for restoration projects, this chapter is intended as a guide for those who choose to produce their own propagules. It covers general requirements and considerations for culturing a variety of aquatic plants, including submersed, floating-leaved, and emergent growth forms. Specific information on several common North American species is given in Appendix A.

Plant Growth Requirements

Considerations

The key to growing any plant is to provide conditions that allow the plant to fulfill its need for nutrients and sustain a rate of photosynthesis sufficient to provide for respiration and growth. All plants have a basic need for water and an environment that provides appropriate temperatures. Beyond these basic requirements, photosynthesis depends on adequate levels of light and a continual supply of inorganic carbon (dissolved carbon dioxide or bicarbonate), while nutrient uptake depends on a supply of critical nutrients. Table 1 lists sites of nutrient uptake and photosynthesis for terrestrial and aquatic plants of different growth forms. These facts must be considered in development of plant culture methods and facilities.

Table 1
Predominant Sites of Nutrient Uptake and Photosynthesis in Terrestrial and Aquatic Plants of Different Growth Forms and Implications for the Culture of Aquatic Plants

Growth Form (example)	Photosynthetic Medium	Provide Inorganic Carbon By	Nutrient Uptake	Add Nutrients To
Terrestrial plants	Air	--	Soil	Soil
Rooted, submersed (*Vallisneria americana*)	Water	Aeration, mixing, water exchange, bicarbonate addition	Sediment	Sediment, very sparingly to water
Nonrooted, submersed (*Ceratophyllum demersum*)	Water	Aeration, mixing, water exchange, bicarbonate addition	Water	Water
Floating-leaved (*Nymphaea odorata*)	Air	Ensure adequate ventilation	Sediment	Sediment, sparingly to water
Emergent (*Scirpus validus*)	Air	Ensure adequate ventilation	Sediment	Sediment and/or water
Free-floating (*Limnobium spongia*)	Air	Ensure adequate ventilation	Water	Water

Unlike terrestrial plants, submersed aquatic plants conduct photosynthesis in a water environment. This is important for several reasons:

- The water must be sufficiently clear to transmit adequate light to the leaves.

- If the water contains nutrients, particularly phosphorus, excessive growth of algae can cause problems by reducing light penetration to submersed plants.

- The water must provide a continual supply of inorganic carbon. Diffusion of carbon dioxide in water is slow and the concentration of carbon dioxide can be greatly reduced in water, particularly at pH levels greater than 8.3.

- Algae will compete with submersed plants for inorganic carbon.

Successful culture of rooted submersed aquatic plants depends on the ability to provide adequate nutrients via the sediment to roots and adequate levels of light and inorganic carbon via the water to shoots (Smart and Barko 1985). Because nonrooted submersed aquatic plants must obtain all of these resources (nutrients, light, and carbon) via the water, they are quite difficult to grow under artificial conditions due to competition with algae. For this reason the authors do not at this time recommend culture of coontail, *Ceratophyllum demersum*, and prefer to collect plants of this species from existing natural populations.

Sediment substrate

Submersed aquatic plants will grow in a variety of substrate types, ranging from pure sand to heavy clays. However, for optimum production, a fine-textured substrate with a low to moderate organic content (10-20 percent) is ideal for most species. Sandy substrates are unsuitable as a culture medium because they are generally infertile and added nutrients will diffuse into the water column, causing algal problems. On the other hand, highly organic substrates can be inhibitory to plant growth by fouling the water column (Barko and Smart 1983, 1986). When available, using fine-textured sediments from ponds or lakes in which aquatic plants are known to grow is recommended. If the growth potential of sediments is in doubt, small-scale trails should be conducted to determine sediment suitability for supporting aquatic plant growth.

Because suitable natural sediments may not always be available, the use of commercial potting soils or topsoils may be necessary. For relatively small-scale efforts, bagged soils may be practical. In the selection of a soil for aquatic use, generally the lowest priced product will be the most suitable as it will generally contain the fewest additives. Avoid the use of products that contain nonsoil additives such as vermiculite or perlite. For large-scale projects, local topsoils may be purchased in bulk after ensuring their suitability.

Containers

Production of propagules suitable for transplanting into lakes requires growing plants in pots. Commercial nursery pots with drain holes in the bottoms are recommended. Holes allow movement of dissolved nutrients into the sediment substrate where they can be taken up by the roots. Various sizes and shapes of commercial nursery pots are available, but quart- (4-in.- or 10-cm-diameter) and gallon- (6-in.- or 15-cm-diameter) sized (nominal sizes) pots have been most

successful for growing a wide variety of aquatic plant species. For economy, acquisition of blow-molded plastic pots permits reuse of at least several times.

Fertilization

Submersed aquatic plants. For short-term (single growing season or less) cultivation of submersed aquatic plants, an initial fertilization of the potting medium is usually sufficient. Often, addition of nitrogen is required to achieve optimum growth (Smart et al. 1995). Ammonium sulfate at rates of 5 g per liter of medium (1 g nitrogen per liter of medium), sufficient to support growth during this period is generally used. While other compounds may be used as a source of nitrogen, it should always be added as an ammonium salt, not as nitrate or urea (which are rapidly lost from anaerobic sediments by diffusion and denitrification).

Longer term cultivation of submersed aquatic plants may require periodic addition of nitrogen and/or other nutrients. Adding nitrogen as either ammonium or nitrate to the water every few weeks can be used to sustain the growth of mature transplants. Because excess levels of nitrogen can be inhibitory to the growth of submersed aquatic plants, concentrations should never exceed 1 or 2 mg/L.

Floating-leaved and emergent aquatic plants. Floating-leaved and emergent growth forms generally produce more biomass than do submersed forms and have proportionately greater demands for nutrients. For this reason, larger quantities of fertilizer should be added to the sediment substrate. Because these forms have their photosynthetic and carbon uptake surfaces in the air rather than the water, excessive algal growth generally does not interfere with their growth. In fact, once they develop a canopy of leaves, these plants may shade out algae. Long-term growth of cultures of these growth forms can be sustained by adding nutrients directly to the water without concern. Although these growth forms generally are not well adapted to absorb nutrients from the water, transpiration drives a movement of water (and dissolved nutrients) into the root mass. For this reason, pots with ample drain holes are preferred so that roots will be in close association with the water.

Water quality requirements

While floating-leaved and emergent plants are not as particular, a reliable source of high-quality water is required for growing submersed aquatic plants. Ideally, water should be clear and relatively nutrient-free (at least phosphorus-free). Clear water allows adequate light penetration. Under low light conditions, some plants will become leggy and produce weak root systems. Nutrient-rich water often leads to algal blooms that can interfere with plant production by competing for light and inorganic carbon. Municipally treated water is not recommended, unless chlorine is first removed. Additionally, treated water also often contains relatively high levels of phosphorus.

For tank cultures, the authors use lake water that has been polished or treated to acceptable quality. In one method, a vegetated pond is used to reduce turbidity and remove most dissolved phosphorus from the water column; water is pumped directly from this pond to the culture facilities. In a second method, lake water is pumped into a holding tank where it is treated with aluminum sulfate (approximately 0.1 kg per 1000 L) to flocculate clays and suspended material and to remove phosphorus by sorption onto precipitates. The resultant flocculent is allowed to settle and clear surface waters are pumped to culture tanks. For a large-scale plant production system, a 1.5-m-deep, lined water supply pond is used as a reservoir. Lake water is pumped into the pond, treated with aluminum sulfate, and mechanically filtered with sand filters (Dick et al. 1997). The pond liner (synthetic rubber) prevents nutrients and clay minerals from being released or suspended from the soil into the water column. This system provides an abundance of high-quality water.

Additional requirements for water used to grow submersed aquatic plants include a source of inorganic carbon and a balanced chemical composition including calcium, magnesium, and potassium ions (Smart and Barko 1984, 1985). Part of the water may be replaced periodically to maintain favorable levels of alkalinity, dissolved inorganic carbon, and dissolved ions. Alternatively, additions of sodium or potassium bicarbonate and calcium (as either a sulfate or chloride salt) can be used to maintain adequate levels of these constituents. Aeration (see following paragraph) is also needed to maintain a steady supply of inorganic carbon.

Water circulation and mixing

In unlined earthen ponds, sediment respiration provides an abundant and continuous supply of carbon dioxide to support the photosynthesis of submersed aquatic plants. However, in lined ponds or tanks, carbon dioxide availability may be a factor limiting growth of submersed aquatic plants (floating-leaved and emergent species acquire carbon dioxide directly from the air, and are therefore not of concern). Consequently, aeration of tank cultures is recommended for submersed species. A regenerative blower/compressor aeration system is required to supply the air, and vigorous bubbling of atmospheric air through air stones usually provides adequate mixing in addition to supplying carbon dioxide.

Production Facilities

Production of aquatic plant propagules requires adequate facilities, but these need not be complicated or expensive. Small ponds or tanks may be used to grow aquatic plants. To minimize transportation costs and inevitable damage that occurs during transport of plant materials, production facilities should be as close as possible to the restoration site. In this regard, in-lake production, if possible, is sometimes the most economical means of propagule production. The following section provides guidelines on the suitability of various facilities for plant production.

Small ponds

Properly designed ponds offer excellent sites for culturing aquatic plants. Although any pond that has reliable water source and water depth will suffice, those with easy drainage and filling serve best. This allows the grower to manipulate water levels for cultivation needs such as planting, weeding, fertilizing, and harvesting. Because the objective is to produce robust, potted transplants, growth should be restricted (as much as possible) to the containers. Earthen pond bottom sediments allow growth of endemic vegetation and encourage the escape of cultivated plants. These situations are undesirable because plants growing wild in the pond reduce the growth of potted plants by competition and interfere with maintenance and harvesting operations. For these reasons, lined ponds are preferred. Construction of concrete pads on earthen pond bottoms offers the same advantage.

Segregation of plant species within a lined pond can be critical for successful cultivation of many species. Cross-contamination by faster (or earlier) growing species can reduce production of slower (or later) growing plants. Because many aquatic plants spread vegetatively from fragments, care must be taken when selecting species for polyculture within a single pond. Isolating fragment-spreaders or prolific seed producers in their own pond is highly recommended. A second option is to construct enclosures for these species. Fine-mesh shade cloth fencing will serve to prevent spread by fragmentation of all species of aquatic plants discussed in this handbook.

Tanks

Tanks are excellent vessels for growing aquatic plants. The advantages of tank culture include accessibility, water quality management, and separation of species. Many sizes and shapes of fiberglass and plastic tanks are available commercially. While these are generally manufactured for aquaculture of fish and invertebrates, some models are well suited for culturing aquatic plants. When selecting tanks, ensure that tank depth is suitable for the species of plants to be cultivated. Another consideration is tank dimension. Easy access is critical to good plant cultivation. A tank width of about 1 m is the maximum for easy access to plants. For many species of submersed and floating-leaved plants, tanks in the range of 0.5 to 1.0 m deep by 1.0 m wide by appropriate length (5 or more m) are recommended. For ease of operation, tanks should be accessible from both sides. Shallow tanks (25 cm or less) are suitable for emergent species.

Construction of custom tanks may be desirable and cost-effective on many projects. For long-term cultivation, concrete vats can be made to size for specific plant types. Permanent plumbing, including filling and drainage piping, can be included in such structures. Less expensive custom tanks can be constructed from available building materials (lumber or concrete blocks) and pond liner material.

Shelters

Greenhouses, hothouses, and cold frames can be incorporated into tank designs to extend the growing season for many plant species. Some degree of protection may be needed for plants in northern areas, where water in tanks can freeze solid. An advantage to moderating temperatures (and possibly photoperiod) is early season production of plants; i.e., mature transplants can be produced, ready for transplanting as soon as project conditions allow. Without temperature and/or light control, most native plants will remain dormant until temperatures rise in the spring, reducing the transplant window during a particular season.

Excessive solar heating can be a serious problem, especially in aboveground tanks. Hot, sunny days may cause excessively high temperatures within tank cultures, and plants may suffer high mortality. Because excessive light can also damage submersed aquatic plants, covering tanks with a light grade (30 percent reduction of sunlight) shade cloth is recommended. This will reduce both light intensity and temperature. Shading for floating-leaved or emergent species is not recommended.

In-Lake Production

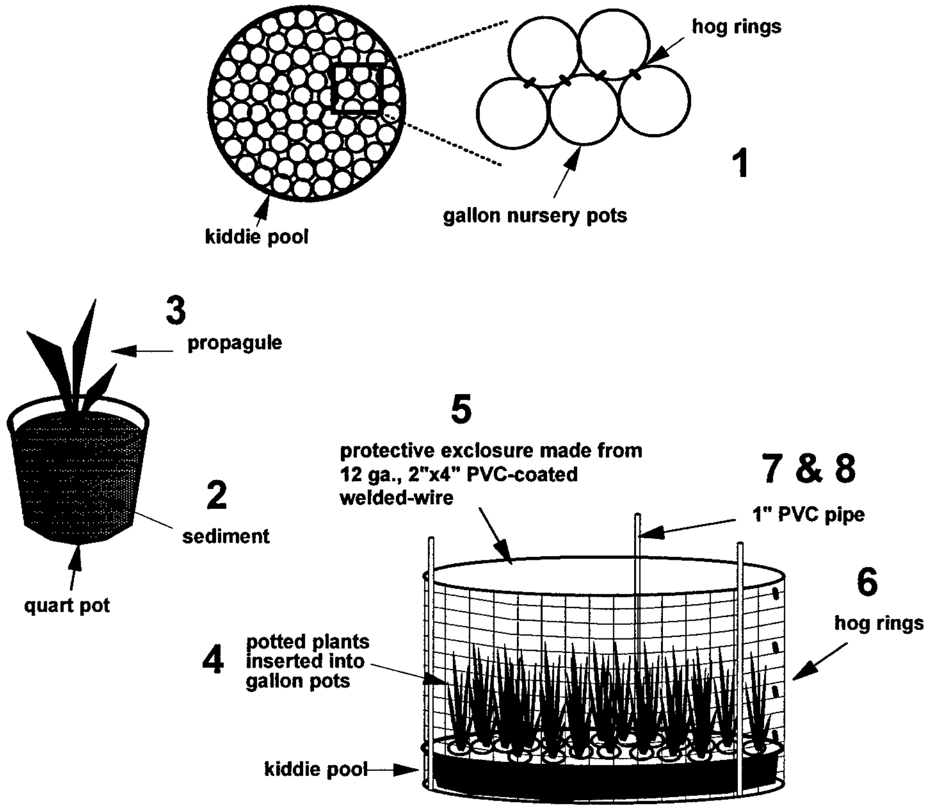
In-lake cultivation may be preferred for some projects, especially when available culture facilities are located some distance away from the project. Transportation of mature transplants over long distances can be logistically difficult and stressful to the plants. In these cases, construction of plant production nurseries within the project water body is recommended.

A simple design illustrates the basic components of an in-lake nursery (Figure 1). A large but movable container (such as a kiddie pool) for holding and stabilizing the pots and a protective fence to prevent grazing (and other disturbances) are required. Pots are filled with lake sediments and planted with propagules (from local or other sources), and plants allowed to grow within the protection of the fencing. When plants are mature, they are moved to designated sites and transplanted. Empty pots are refilled with sediment substrate, and a subsequent crop is started to ensure a continued supply of mature transplants (or other propagules) throughout the growing season.

Planting the Containers

The general procedure for "making" potted aquatic plants (mature transplants) is as follows:

- Fill pot to about 1/4 full (covering drainage perforations) with potting medium.
- Add an appropriate dose of fertilizer.
- Fill the remaining 3/4 of the pot with potting medium.
- Place pots in growing vessel (pond, tank, etc.)



1. **Attach gallon pots together with hog rings to fill kiddie pool.**
2. **Fill quart pots with sediment.**
3. **Plant propagules in quart pots.**
4. **Insert potted plants into gallon pots.**
5. **Form a ring cage with protective fencing to fit kiddie pool.**
6. **Fasten ends of ring cage with hog rings.**
7. **Weave PVC pipe through ring cage mesh.**
8. **Push PVC pipe into sediment until firmly anchored.**

Figure 1. In-lake production may be most economical for some projects

- Slowly fill the growing vessel to 10 or 15 cm above the pot with clean water to saturate the potting medium.
- Allow filled pots to cure for one to several weeks - particularly if using a nonaquatic substrate. An initial nutrient pulse is generally observed as some nutrients and organics are released into the water. This is evidenced by greening of water (algal bloom), brown staining of the water by humic materials, or by the presence of an organic film on the water surface. Flush the water and refill several times if necessary.
- Make an indentation in the center of the potting medium.
- Plant the propagule, and backfill to ensure that the plant is anchored.
- Fill the growing vessel to the desired cultivation depth with clean water.

Propagule Types

Many commercial suppliers (collectors) sell aquatic plant propagules. Using these propagules is generally not recommended for establishing plant colonies in lakes and reservoirs, but they are often adequate as starter materials for plant propagule production in tanks or ponds. Availability is often seasonal, and locality concerns should be carefully weighed. If local or regional populations of a particular species are known, harvesting from these populations is recommended to obtain starter propagules.

Stem fragments, daughter plants, root crowns, tubers or winterbuds, even seeds (usually dependent upon species) may be used as starter materials for aquatic plant cultures. Planting more pots than needed for a project is suggested if other projects are planned in the future. After a culture of a particular species is established, it can be used as a source for the next generation of cultivation. This prevents excessive damage that might be inflicted on donor populations if repetitive annual collections were required.

Stem fragments

Many aquatic plant species spread vegetatively from stem fragments. These species have apical meristems at the terminal ends of the shoots. To propagate new plants from stem fragments, cut healthy stem tips to a length of 15 to 20 cm. When selecting material remember that the greater the density of leaves along the stem, the better, as most nodes can produce roots as well as leaves and branches. Plant cuttings to a depth of about 10 cm in the potting medium, leaving the apical tip exposed for growth. For faster development, several cuttings should be planted per pot. Established plants readily regenerate new meristematic tissues after cutting, so once the culture is actively growing, cuttings can be taken to plant additional pots.

Rosette plants

Some aquatic plant species grow in a rosette form that produces daughter plants along stolons. To propagate these species, clip small plants from the parent and plant directly into pots. These plants have a basal meristem, and care must be taken not to cover this growing area excessively when planting. A relatively dense, firm substrate is important for these species because they are buoyant and, without sufficient anchoring, are easily dislodged from the potting medium. A layer of coarse sand or fine gravel can be placed over the substrate after planting to help anchor the plants. Once plants are established, additional plantings can be made by removing daughter plants as they appear on stolons or by dividing potted plants.

Dormant perennating plants

Many aquatic plants perennate by producing tubers or winterbuds that survive winter or dry periods in a dormant state. Using tubers or winterbuds is an

excellent way to start a culture. Dormant propagules can be collected, held in a dormant state by refrigeration (for up to 6 weeks), and then planted when desired. Some tubers are buoyant, and should be planted about 10 cm deep and covered completely with potting medium. Extra pots (or larger containers) can be prepared and plants held over to complete their annual life cycle either to produce tubers that can be harvested and used for restoration projects or to produce subsequent crops.

Appendix A lists the types of propagules recommended as starter materials for producing transplants of selected aquatic plant species.

Culture Maintenance

Weeds

As with any culture or crop, nuisance weeds may cause problems. Pond sediments often contain seeds and spores of aquatic species that might interfere with production of desired species. Although the process is expensive and labor-intensive, sediments can be heat sterilized to avoid or reduce this problem. Regardless, hand weeding will be required to remove unwanted plants, but this also is time-consuming and labor intensive.

Inadequate separation of plant species in mixed pond or tank cultures can also lead to cross-contamination and weed infestations, especially where production of single-species transplants is critical. Growing monocultures in separate tanks will usually prevent cross-contamination. If contamination does occur, rigorous hand weeding will be necessary to correct the problem.

Algae

Excessive algal growth is always a concern with cultures of submersed aquatic plants. High concentrations of nutrients (especially phosphorus and nitrogen) in the water column will generally support excessive algal growth. Algae, whether growing in the water, on the water surface, or on the plants themselves, cause problems by reducing growth of desired plants. Algae compete with macrophytes for light, nutrients, and inorganic carbon, and, because they are capable of rapid growth, can quickly become problematic. Once algae become well established in a culture, they are difficult to control so prevention is prudent. As mentioned earlier, using low-nutrient water and avoiding excess fertilizer will usually prevent algal problems. Reduction of existing algal blooms will require exchanging the water with low-nutrient water and either removing filamentous growths by hand or filtering the water to remove phytoplankton.

Grazing pests

Herbivore damage may become a problem in some situations. Pond and in-lake plant cultures must be protected from turtles, carp, waterfowl, muskrats, and some invertebrates. Protective devices are discussed in the following chapter.

Aphids and caterpillars can reach nuisance proportions in tank cultures, and may require control by spraying with water (aphids) or application of garden-use *Bacillus* products (caterpillars).

3 Implementation

Site Selection

Founder colony sites should be selected based upon several criteria. Choose shallow (<2-m depths) coves—preferably with gradual slopes—well protected from winds and wave action for establishment of aquatic plants. A fine-textured substrate is most suitable, and generally indicates a favorable, low-energy environment. Areas of high sediment resuspension and thus high turbidity can usually be avoided by selecting such wind- and wave-protected coves. These are generally the clearest shallow waters available.

Other than as an indicator of physical conditions, sediment texture does not seem to be critical to successful establishment, and sandy to muddy substrates have had similar results. The major consideration is that plant roots must be able to penetrate the sediment to a depth of at least 15 cm in order to anchor the plant.

Although there have been very few problems with vandalism of sites, avoiding high-use areas such as developed shorelines and areas favored by bank anglers, swimmers, and users of recreational watercraft is recommended. In addition, heavily wooded shorelines can be a problem due to excessive shading, which greatly reduces the light available to submersed aquatic plants. Areas with signs of heavy animal activity—particularly hogs, cattle, or beaver—should also be avoided.

Planting Depth

The two greatest abiotic influences on aquatic establishment are water level fluctuations and high turbidity. Because submersed aquatic plants require light to survive, planting at proper depths is critical, particularly if the water is turbid. Water levels of most reservoirs are influenced by both natural (seasonal or climatic) events and operations (storage or release of floodwaters or water supplies, power generation, etc.), both of which are generally beyond control. For planning purposes, review historic water level fluctuations to estimate expected levels during early establishment. Based on expected water levels and knowledge of the biology of the plant species, assign an appropriate depth or depth range for each species. In general, submersed plants will establish best at depths of 0.5 to 1.0 m, floating-leaved plants from 25 to 75 cm, and emergent plants from 0 to 25 cm.

Species Selection

Using only native plant species is suggested, as these tend not to reach weedy proportions, reducing the likelihood of future problems. Establishing as great a diversity as possible is also suggested to ensure long-term establishment of at least some species (e.g., drought-tolerant species will survive long drawdowns, while others may not). Diverse communities of native plants also provide the greatest water quality and habitat benefits over the long term.

Plants should be selected based on specific lake habitats or anticipated environmental conditions. For instance, in a lake known to follow a pattern of water elevation change, concentrating on drought-tolerant species may be best. However, because predicting environmental changes in a reservoir is difficult, conducting a test planting of as many species as possible is strongly recommended to ensure an adequate evaluation.

Species that have demonstrated potential for lake restoration are provided, along with information about their culture and planting, in Appendix A.

Timing

Timing can be as critical as species selection. Planting should occur before or during periods of active growth to ensure establishment. Unlike seeds or less robust propagules, mature transplants can be planted over a wider seasonal range. Depending on location, this may range from midspring to late summer. In reservoirs that experience spring floods, planting should be delayed until water levels drop to their normal summer levels. In general, plants should be planted as early as practicable. Establishment of a viable population from mature transplants is possible in late summer, but late planting reduces the length of growing season remaining and may decrease the likelihood of success.

Herbivore Protection

Establishment of new colonies of aquatic plants in unvegetated reservoirs requires protection from herbivores (Smart et al. 1996; Doyle et al. 1997). Several types of protective exclosures have been used, depending on the expected level of herbivory. Site visits, discussions with lake and fisheries managers, and trapping can provide preliminary estimates of the densities of herbivorous species that may be encountered.

Several of the following small-scale exclosures provide near-complete protection from herbivory if constructed of appropriate materials and properly deployed. However, because these exclosures protect only a single, relatively small clump of plants, they may be most useful in situations where herbivory is low to moderate. Larger herbivore exclosures offer protection from omnivores such as carp and other rough fish. These are used in situations where rough fish population densities are expected to be high, or in reservoirs previously stocked with grass carp.

Individual plant protection

Cylinders constructed of wire-mesh fencing can provide economical and reliable protection for individual transplants. Cylinders 60 to 90 cm in diameter by 91 or 122 cm (3 or 4 ft) high, constructed from 2- by 4-in. (nominal size) mesh welded-wire fencing and anchored with 152- or 183-cm (5- or 6-ft) lengths of rebar, have been used successfully (Figure 2). The rebar is woven through the mesh material and driven into the sediment to secure and anchor the cylinder. Alternatively, two pieces of rebar can be driven into the bottom (on the inside of the cylinder) and the cylinder secured to them with black (ultraviolet radiation resistant) plastic cable ties. For submersed plants placed in depths where the water level will be near the top of (or may sometimes overtop) the exclosure, opposite sides can be cinched together with wire ties or cable ties (between the two pieces of rebar) to close the top and prevent entry of turtles and other herbivores.

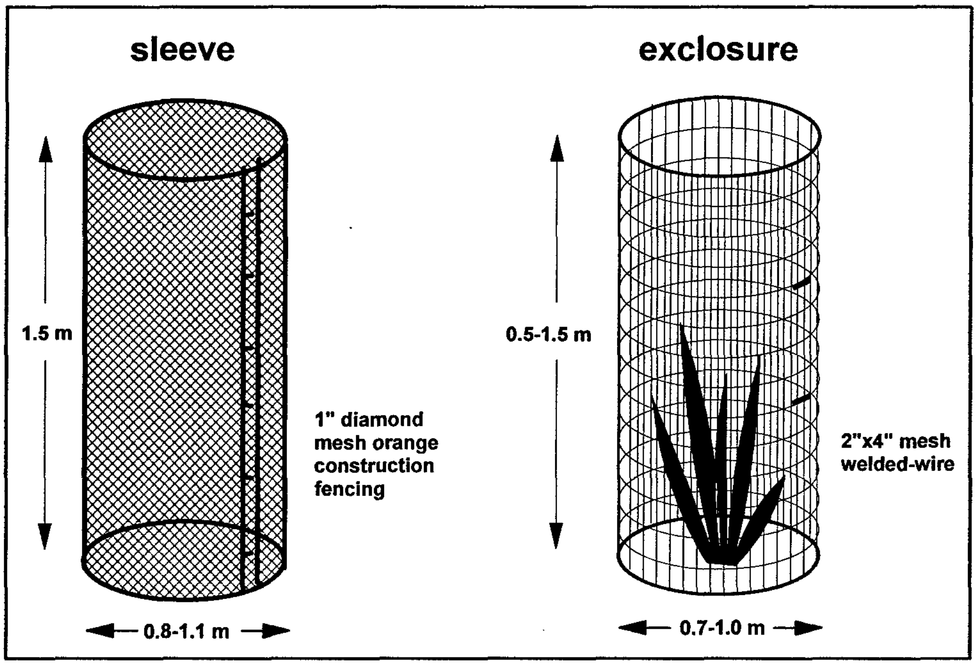


Figure 2. Individual plant protection cylinder

These individual plant exclosures are designed to protect single transplants from larger omnivores such as adult turtles, carp, nutria, etc. If protection from juvenile turtles and/or crayfish is needed, exclosures can be made from finer mesh material. Alternatively, a sleeve of a finer mesh material (such as orange plastic construction fencing) can be placed over the wire mesh cylinder (Figure 2). The advantage of this approach is that the sleeve can likely be removed and reused after initial establishment of the transplant.

Multiple plant protection

Larger exclosures protect multiple plants. These can be constructed of wire-mesh fencing or orange plastic construction fencing. Square cages 150 or 180 cm

(5 or 6 ft) on a side, constructed of 122- or 183-cm (4- or 6-ft) high, 1-in. diamond mesh (nominal size) orange plastic construction fencing, rebar, and PVC piping have been used successfully (Figure 3, Smart et al. 1996). These exclosures can be assembled on shore, rolled up, and transported to the planting locations when ready. At the site, a four-person crew sets the corners, ensures that the bottom flap is folded out to form a flange, and anchors posts 1 through 4. The shorter fifth piece of rebar is used to secure the opening after planting. Precut and drilled lengths of 2-in. polyvinyl chloride (PVC) piping (nominal size) are placed over the rebar to stiffen the exclosure and prevent turtles from climbing over the top. These can be secured with black plastic cable ties, and, if necessary, the fence fabric can be secured to the PVC with similar ties.

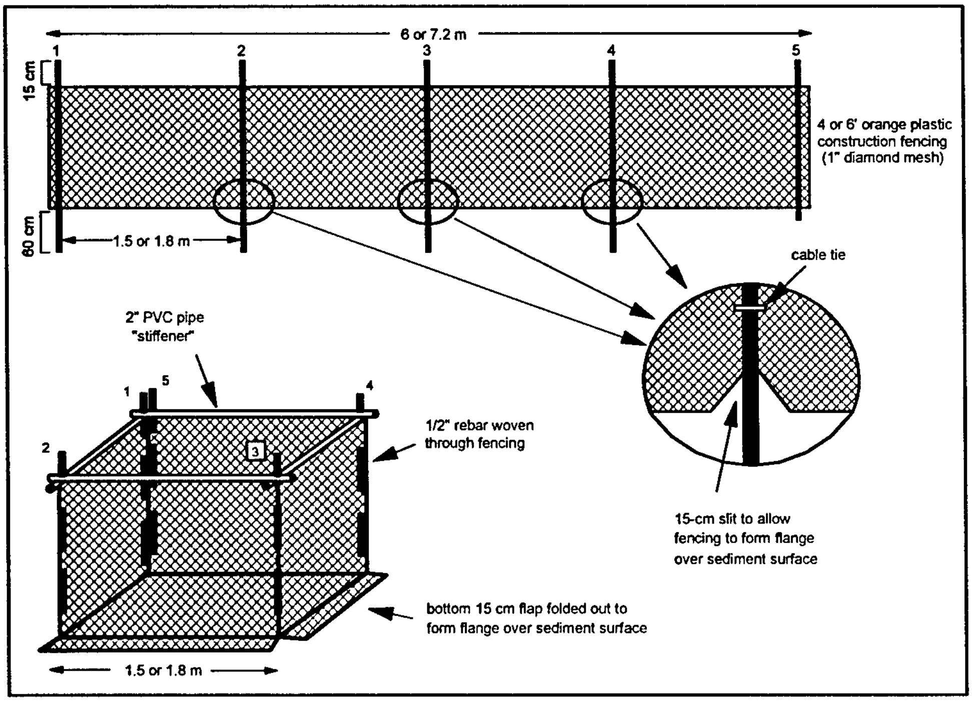


Figure 3. Multiple plant exclosures can be constructed beforehand and installed during planting. Dimensions in non-SI units are nominal sizes

These multiple plant exclosures are usually planted with four or five transplants and may be suitable for harsh environments where survival of an individual transplant may be in doubt. The larger area of the resultant population may also sustain a higher grazing pressure than would an individual plant unit. An additional advantage is that the material is highly visible, making the exclosures easy to find for monitoring and evaluation and easy for boaters to avoid. Drawbacks include greater expense, difficulty of construction, and less durability in comparison with wire-mesh exclosure designs.

Design of another type of larger exclosure (hoop cage) borrows from wire mesh cylinders. Heavier, more durable materials are used to construct hoop cages large enough to protect multiple plantings. Typically, the diameter of these cylinders is at least as great as the height, about 1.8 or 2.1 m (6 or 7 ft), reducing stem and leaf abrasion against the mesh. PVC-coated galvanized welded wire (2- by 4-in. mesh, nominal size) is used, and, if needed, additional support is provided

by affixing black plastic irrigation tubing (1-in. diameter, nominal size) to the top and bottom rims of the cylinder with cable ties. Three pieces of 1-in.-diameter (nominal size) schedule 40 PVC piping are used to anchor the cage to the substrate, much as the rebar is used in the smaller cylinders described previously.

Fenced plots protect even larger planted areas, generally 3 m or greater on a side. Square or rectangular fenced plots constructed from T-posts and 122-, 152-, or 183-cm (4-, 5-, or 6-ft) high, 2- by 4-in. mesh welded-wire fencing have been used (Figure 4). T-posts are placed on 2.5- to 3.5-m centers and the fencing attached with wire ties. The interface between the fence and the bottom sediment is critical, and an outward flap at the bottom of the fence helps prevent entry of turtles, carp, and other large grazers.

Fenced plots are planted at a density of 0.4-0.8 plants/m^2. These larger exclosures may be most suitable for reservoirs that are expected to have high numbers of carp and/or other waterborne grazers.

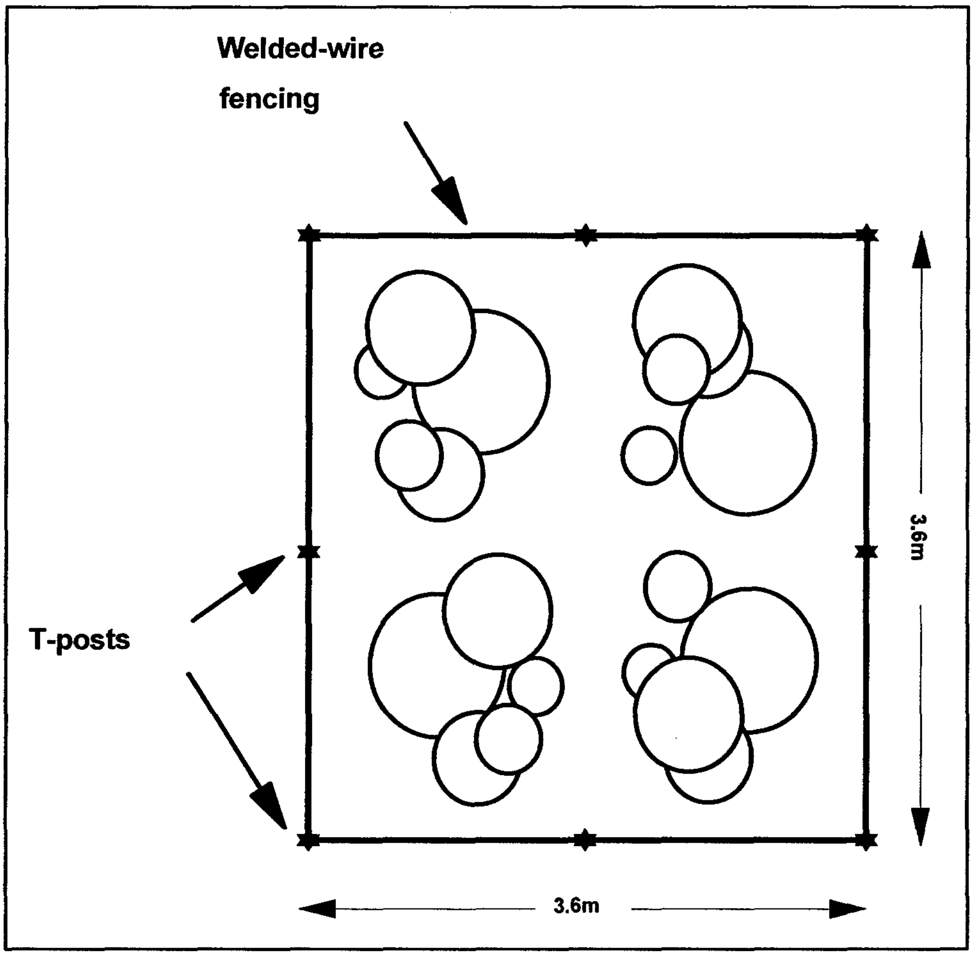


Figure 4. Fenced plots are constructed to protect moderately large founder colonies

Shoreline fences are three-sided modifications of this fenced plot design (Figure 5). These are irregular in size, extending from the shoreline out to, for

example, the 1-m contour and then along that contour parallel to the shore. These are also constructed of 122-, 153-, or 183-cm (4- or 6-ft) high, 2- by 4-in. mesh (nominal size) welded-wire fencing attached to T-posts. Erosion fencing may be attached to shoreline fences to reduce effects of wave action (silt fences).

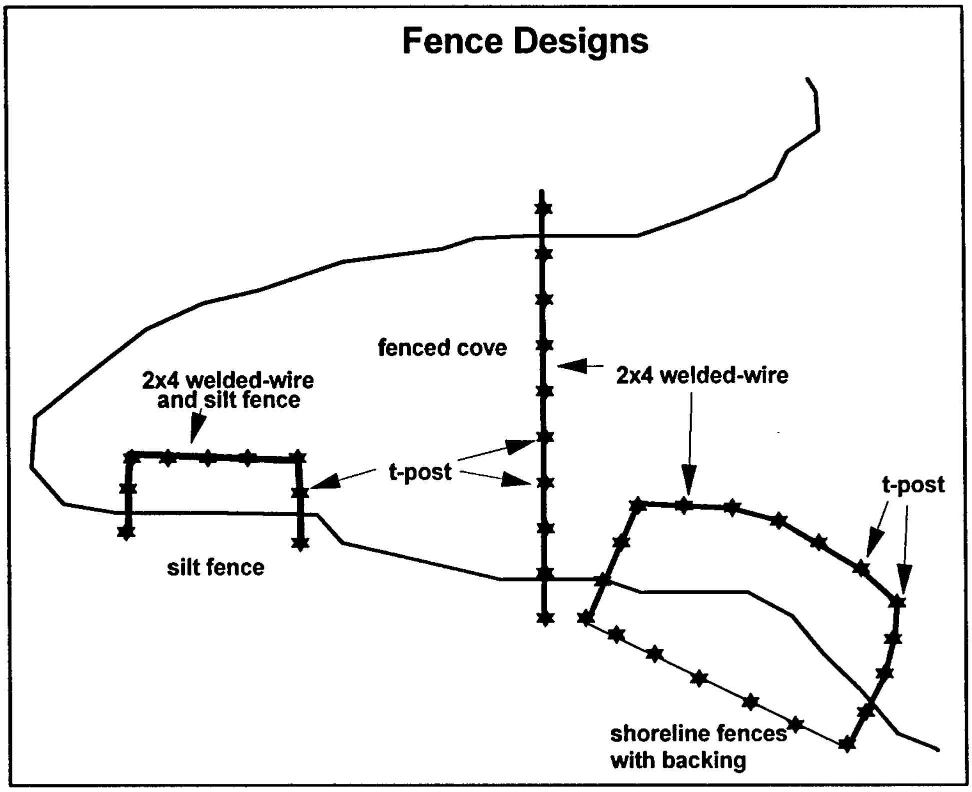


Figure 5. Shoreline fences and fenced coves protect relatively large founder colonies

Because shoreline fences do not exclude herbivores that can move over land (turtles, nutria, muskrat, beavers), plants may require a double layer of herbivore protection (individual plant exclosure plus the shoreline fence). Optionally, a backing can be installed to completely enclose the fenced area, effectively producing a shoreline fenced plot. Areas enclosed by shoreline fences should be planted at densities similar to those for fenced plots.

In some cases, cove areas are isolated from the main body of the reservoir with fences constructed of 2- by 4-in. mesh (nominal size) welded-wire fencing and T-posts. Construction is similar to that for fenced plots except that the fence is placed across the mouth of a small cove (Figure 5). Water depth at the deepest portion of the cove opening should be considered when selecting cove sites. If maximum depth exceeds 1.5 m, the design may require alteration to increase strength and rigidity. For strength and appearance, the top of the fence should be level. Because depth will vary across the cove opening, different fence heights can be used to ensure that the fence contacts the bottom.

Like shoreline fences, fenced coves do not exclude herbivores that can move over land, and plants may require a double layer of herbivore protection

(individual plant exclosure plus the cove fence). Enclosing the open sides of the cove fence is generally not practical. Avoid coves with large, inflowing creeks because the fence will trap logs and other debris and may be subject to damage or undercutting during high flow events.

Monitoring and Redirecting

Once suitable sites are selected and exclosures constructed, the restoration project should proceed in three phases. Phase 1 involves planting and monitoring over a full growing season of test plants of a variety of species within small protective exclosures. Assuming suitable sediments, water quality, and water levels, these plants will establish and expand beyond their protective cages, depending on the level of herbivory. During Phase 1, the level of herbivory and, if possible, the sizes and types of herbivores, should be noted. Monitoring during Phase 1 is important because the response of the plants will dictate the best course of action to take during subsequent growing seasons.

During the second growing season, those species performing best during Phase 1 should receive additional plantings. However, in many unvegetated reservoirs, expansion of the plantings will require provision of a larger scale protected environment such as a fenced cove. Phase 2 may involve construction of a fence across the cove mouth to exclude carp and other rough fish in combination with additional plantings of selected or preferred species. Phase 2 should result in the successful establishment of founder colonies of several species.

During Phase 3, colonies expand to fill the niche within the fenced cove, and begin to spread into unprotected areas by vegetative and/or sexual modes of reproduction. Monitoring should be continued at this stage, as large-scale disturbances can have serious consequences on newly established plant communities. Additional species may also be desirable to ensure maximum diversity, stability, and resilience of the aquatic plant community.

Sustaining Founder Colonies

It has been the authors' experience that planting potted plants in southern reservoirs results in rapid colonization of planted species within protective exclosures. Once plants reach the borders of exclosure protection, however, their rate of spread is greatly reduced or even halted, typically due to intense levels of grazing occurring outside the fences and cages. Periodically during the growing season, plants seem to get ahead of herbivores, resulting in spread to unprotected areas. This usually occurs in conjunction with falling water levels, and it is believed that aquatic grazers are less likely to impact plants found in very shallow depths (15 cm and less), thus permitting at least temporary establishment of plants from fragments and other propagules in otherwise unprotected areas. In some cases, when water levels return to normal, herbivores move in and eliminate the unprotected colonies. However, in some cases, enough spread has occurred (presumably relative to herbivore populations) that the unprotected

colonies persist. It is hoped that these latter cases are achieved in all reservoir restoration efforts.

For this to occur, well-established founder colonies must be in place at all times during the growing season so that propagules for natural spread are present in sufficient numbers when conditions are met. In order to ensure founder colonies are present at all times, the same two obstacles that must be overcome to establish them (water level fluctuations and herbivory) must be dealt with in the longer term.

Planting at multiple depths

Because many reservoirs serve as flood control and municipal water supplies, water levels are expected to fluctuate, in some cases quite significantly. Founder colonies planted at a single depth relative to conservation pools may well spend much of the year out of water or under too great depths for plant growth, and those times during the year in which water depths are ideal may not seasonally coincide with the growing seasons of particular species. Establishing founder colonies at multiple depths increases the possibility that plants will be actively growing and producing propagules for natural spread throughout the growing season.

A planting schedule has been devised that allows for development of founder colonies at multiple elevations under fluctuating water level regimes. Typically, submersed plants are planted at 0.8- to 0.9-m (2.5- to 3-ft) depths, floating-leaved plants at 0.6-m (2-ft) depths, and emergent species at 15- to 30-cm (1/2- to 1-ft) depths. When water levels in a reservoir drop (or rise) by 0.5 m (2 ft), new exclosures are constructed and planted using the same depth schematic. In a typical Texas reservoir, water levels may fall throughout the growing season, and establishing three or more depth tiers of plants is common. Plants exposed to desiccation (or too great depths) generally decline, but often recover when water levels return to suitable depths. Once colonies are in place at multiple depths, water level fluctuations are less likely to impact growth of founder colonies, and continuous production of propagules may be achieved.

Exclosure maintenance

Continued protection of founder colonies from herbivores is critical to their successful establishment and subsequent spread. Materials used in exclosure construction vary in their ability to withstand the ravages of underwater installation. For instance, galvanized welded wire may remain functional only one or two growing seasons before the galvanization dissolves and the wire rusts. Plastic mesh is susceptible to ultraviolet degradation and damage by beaver, nutria, and muskrats. PVC-coated welded wire is stronger and longer lived than other types, but, along with the others, can be damaged by floating logs, boats, or large animals (such as cattle). In addition to damage to materials, larger herbivores, such as beaver, frequently dig under fences either to gain access to plants or to reach the back of coves fenced off from the reservoir. These openings provide access to smaller herbivores such as turtles and carp.

Because exclosures are subject to breaches of many types, including a scheduled maintenance program in any restoration project is recommended. Exclosures should be inspected as frequently as possible, and when damage is noted, repairs should be made.

High water levels may sometimes overtop exclosures. In these cases, after water levels have fallen below the tops of the cages, any herbivores that may have been trapped within the exclosure are removed. Carp and turtles can be removed with seine nets, while turtles alone can be trapped with floating fall-in traps.

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Appendix A Aquatic Plant Restoration Candidate Species

Wild Celery (southern)	
Species	
Scientific name	*Vallisneria americana* (southern ecotype)
Common names	Wild celery, eelgrass, tapegrass, ribbon grass, vallisneria
Growth Characteristics	
Growth form	Rooted submersed. Grows in a rosette form with a basal meristem and ribbonlike leaves.
Reproduction	Dioecious (individual plants are either male or female); proliferates vegetatively by producing daughter plants along stolons and sexually by seed.
Perennation	Evergreen perennial
Range	Southern United States
Use	Valuable for fish habitat and waterfowl food in the southern United States. Evergreen habit allows planting over an extended period and allows growth during much of the year.
Culture	
Plant	Daughter plants from early spring to late summer
Produce	Mature transplants
Light	50 to 75 percent full sunlight
Container	4-in. (1-quart) nursery pots
Substrate	Well-cured terrestrial soil or sterilized aquatic sediment
Fertilization	2 g ammonium sulfate per quart of potting medium. Supplement by adding approximately 1 mg ammonium nitrogen/L to the water column every 4 weeks during active growth.
Water depth	50 to 100 cm
Comments	Slow to start, with a minimum of 12 weeks required for production of mature transplants. Topped out leaves are susceptible to aphid infestation. Snails can be a problem at high densities.
Field Planting	
Propagule	Mature potted transplants
Season	Early spring to early fall
Substrate	Sand to muck
Depth	50 to 100 cm
Comments	Transplants must be planted deep enough to cover the root mass and anchor the plant, but care must be taken not to bury the basal rosette. Highly prone to herbivory by turtles and waterfowl.

Wild Celery (northern)	
Species	
Scientific name	*Vallisneria americana* (northern ecotype)
Common names	Wild celery, eelgrass, tapegrass, ribbon grass, vallisneria
Growth Characteristics	
Growth form	Rooted submersed; grows in a rosette form with a basal meristem and ribbonlike leaves.
Reproduction	Dioecious (individual plants are either male or female); proliferates vegetatively by producing daughter plants and winterbuds along stolons and sexually by seed.
Perennation	Herbaceous perennial; overwinters as dormant winterbuds.
Range	Northern United States
Use	Valuable for fish habitat and waterfowl food in the northern U.S. Winterbuds are a preferred food for many species of waterfowl.
Culture	
Plant	Winterbuds in early spring, daughter plants from spring to late summer
Produce	Mature transplants or winterbuds
Light	50 to 75 percent full sunlight
Container	4-in. (1-quart) nursery pots
Substrate	Well-cured terrestrial soil or sterilized aquatic sediment
Fertilization	2 g ammonium sulfate per qt of potting medium. Supplement by adding approximately 1 mg ammonium nitrogen/L to the water column every 4 weeks during active growth.
Water depth	50 to 100 cm
Comments	Slow to start with a minimum of 12 weeks required to produce mature transplants. Topped out leaves are susceptible to aphid infestation. Snails can be a problem at high densities.
Field Planting	
Propagule	Mature potted transplants
Season	Early spring (winterbuds or transplants) to midsummer (transplants only)
Substrate	Sand to muck
Depth	50 to 100 cm
Comments	Transplants must be planted deep enough to cover the root mass and anchor the plant, but care must be taken not to bury the basal rosette. Highly prone to herbivory by turtles and waterfowl.

American Pondweed	
Species	
Scientific name	*Potamogeton nodosus*
Common name	American pondweed
Growth Characteristics	
Growth form	Rooted submersed; produces both submersed and floating leaves on upright shoots produced along stolons.
Reproduction	Proliferates vegetatively by producing new shoots along stolons; also reproduces by fragmentation and winter-bud formation and sexually by seed.
Perennation	Herbaceous perennial; overwinters as dormant winterbuds
Range	Throughout the United States
Use	Valuable for fish habitat and waterfowl food. Floating leaves are adapted for shallow, turbid waters. Winterbuds allow for survival during low water periods.
Culture	
Plant	Winterbuds in early spring, apical cuttings from spring to midsummer
Produce	Mature transplants or winterbuds
Light	75 to 100 percent full sunlight
Container	4-in. (1-quart) nursery pots
Substrate	Well-cured terrestrial soil or sterilized aquatic sediment
Fertilization	2 grams ammonium sulfate per qt of potting medium. Supplement by adding approximately 1 mg ammonium nitrogen /L to the water column every 4 weeks during active growth.
Water depth	50 to 100 cm
Comments	This species can produce field-ready transplants in 4 to 6 weeks. Rapid growth in small containers may lead to completion of the life cycle in about 2 or 3 months. Topped out leaves are susceptible to aphid infestation.
Field Planting	
Propagule	Mature potted transplants (preferred) or winterbuds
Season	Early spring (winterbuds or transplants) to midsummer (transplants only)
Substrate	Sand to muck
Depth	50 to 100 cm
Comments	Less susceptible to herbivory than many other submersed species. When using winterbuds, three to five should be planted together in cotton mesh bags. Well adapted for periods of desiccation.

Illinois Pondweed	
Species	
Scientific name	*Potamogeton illinoensis*
Common name	Illinois pondweed
Growth Characteristics	
Growth form	Rooted submersed; produces both submersed and floating leaves on upright shoots produced along horizontally growing stolons.
Reproduction	Proliferates vegetatively by producing new shoots along stolons; also reproduces by fragmentation formation and sexually by seed.
Perennation	Herbaceous perennial; overwinters as dormant stems
Range	Throughout the United States
Use	Valuable for fish habitat and waterfowl food. Floating leaves are adapted for shallow, turbid waters.
Culture	
Plant	Apical cuttings from spring to midsummer
Produce	Mature transplants
Light	75 to 100 percent full sunlight
Container	4-in. (1-quart) nursery pots
Substrate	Well-cured terrestrial soil or sterilized aquatic sediment
Fertilization	2 grams ammonium sulfate per qt of potting medium. Supplement by adding approximately 1 mg ammonium nitrogen /L to the water column every 4 weeks during active growth.
Water depth	50 to 100 cm
Comments	This species can produce field-ready transplants in 4 to 6 weeks. Topped out leaves are susceptible to aphid infestation.
Field Planting	
Propagule	Mature potted transplants
Season	Early spring to midsummer
Substrate	Sand to muck
Depth	50 to 100 cm
Comments	Moderately susceptible to herbivory. Poorly adapted to periods of desiccation.

Water Stargrass	
Species	
Scientific name	*Heteranthera dubia*
Common name	Water stargrass
Growth Characteristics	
Growth form	Rooted submersed; produces alternate grasslike leaves along upright stems.
Reproduction	Proliferates vegetatively by producing new shoots from short stolons or by fragmentation and sexually by seed.
Perennation	Herbaceous perennial; overwinters as dormant root crown
Range	Throughout the United States
Use	Valuable for fish habitat and waterfowl food
Culture	
Plant	Apical cuttings in early spring to midsummer
Produce	Mature transplants
Light	75 to 100 percent full sunlight
Container	4-in. (1-quart) nursery pots
Substrate	Well-cured terrestrial soil or sterilized aquatic sediment
Fertilization	2 g ammonium sulfate per qt of potting medium. Supplement by adding approximately 1 mg ammonium nitrogen/L to the water column every 4 weeks during active growth.
Water depth	50 to 100 cm
Comments	This species can produce field-ready transplants in 6 to 8 weeks. Topped out leaves are susceptible to aphid infestation.
Field Planting	
Propagule	Mature potted transplant
Season	Early spring to late summer
Substrate	Sand to muck
Depth	50 to 100 cm
Comments	Less susceptible to herbivory than many other submersed species. Surface leaves may develop a waxy cuticle; this plant is well adapted to survive low water periods.

White Water Lily	
Species	
Scientific name	*Nymphaea odorata*
Common names	White water lily, fragrant water lily
Growth Characteristics	
Growth form	Rooted floating-leaved; leaves produced at apical tips of branching rhizomes.
Reproduction	Proliferates vegetatively by producing new shoots along rhizomes; also reproduces by winterbud formation and sexually by seed.
Perennation	Herbaceous perennial; overwinters as dormant rhizomes and winterbuds
Range	Throughout the United States
Use	Valuable for fish habitat and waterfowl food. Floating leaves are adapted for shallow, turbid waters.
Culture	
Plant	Winterbuds or rhizome tips in early spring, rhizome tips from spring to midsummer
Produce	Mature transplants
Light	75 to 100 percent full sunlight
Container	6-in. (1-gal) nursery pots
Substrate	Well-cured terrestrial soil or sterilized aquatic sediment
Fertilization	2 g ammonium sulfate per qt of potting medium. Supplement by adding approximately 1 mg ammonium nitrogen/L to the water column every 4 weeks during active growth.
Water depth	50 to 100 cm
Comments	This species can produce field-ready transplants in 6 to 8 weeks. Leaves are susceptible to aphid infestation.
Field Planting	
Propagule	Mature potted transplants
Season	Late spring to midsummer
Substrate	Sand to muck
Depth	25 to 75 cm
Comments	Less susceptible to herbivory than submersed species; tolerant of low water periods once established.

Softstem Bulrush	
Species	
Scientific name	*Schoenoplectus tabernaemontani* [*Scirpus validus*]
Common names	Softstem bulrush, great bulrush
Growth Characteristics	
Growth form	Rhizomatous emergent sedge
Reproduction	Proliferates vegetatively by producing new shoots along rhizomes; reproduces sexually by seed.
Perennation	Herbaceous perennial
Range	Throughout the United States
Use	Valuable for fish and waterfowl habitat and erosion control
Culture	
Plant	Divided rhizomes from spring to midsummer
Produce	Mature transplants
Light	100 percent sunlight
Container	6-in. (1-gal) nursery pots
Substrate	Most soil types
Fertilization	2 g ammonium sulfate per qt of potting medium. Supplement by adding approximately 1 mg ammonium nitrogen/L to the water column every 4 weeks during active growth.
Water depth	Saturated to 25 cm
Comments	This species can produce field-ready transplants in 6 to 8 weeks.
Field Planting	
Propagule	Mature potted transplants
Season	Early spring to midsummer
Substrate	Sand to muck
Depth	Moist soil to 50 cm
Comments	Susceptible to herbivory by muskrats and nutria. Drought-resistant rhizomes permit survival during low water periods.

Water Willow	
Species	
Scientific name	*Justicia americana*
Common names	Water willow, American water-willow
Growth Characteristics	
Growth form	Rhizomatous emergent forb
Reproduction	Proliferates vegetatively by producing new shoots along rhizomes. Also reproduces by fragmentation and sexually by seed.
Perennation	Herbaceous perennial; overwinters as dormant rhizomes.
Range	Eastern United States
Use	Valuable for fish habitat and erosion control
Culture	
Plant	Apical cuttings from spring to midsummer
Produce	Mature transplants
Light	100 percent full sunlight
Container	4-in. (1-quart) or 6-in. (1-gal) nursery pots
Substrate	Most soil types
Fertilization	2 g ammonium sulfate per qt of potting medium. Supplement by adding approximately 1 mg ammonium nitrogen/L to the water column every 4 weeks during active growth.
Water depth	Saturated to 25 cm
Comments	This species can produce field-ready transplants in 6 to 8 weeks
Field Planting	
Propagule	Mature potted transplants
Season	Early spring to midsummer
Substrate	Sand to muck
Depth	Moist soil to 75 cm
Comments	Highly resistant to herbivory and drought

Flatstem Spikerush	
Species	
Scientific name	*Eleocharis palustris* [*E. macrostachya*]
Common names	Flatstem spikerush, creeping spikerush, common spikerush
Growth Characteristics	
Growth form	Rhizomatous emergent sedge.
Reproduction	Proliferates vegetatively by producing new shoots along rhizome; reproduces sexually by seed.
Perennation	Herbaceous perennial; overwinters as dormant rhizomes
Range	Throughout the United States (except Florida and Georgia)
Use	Valuable for fish habitat, waterfowl food, and erosion control
Culture	
Plant	Divided rhizomes from spring to midsummer
Produce	Mature transplants
Light	100 percent full sunlight
Container	4-in. (1-quart) nursery pots
Substrate	Most soil types
Fertilization	2 g ammonium sulfate per qt of potting medium. Supplement by adding approximately 1 mg ammonium nitrogen/L to the water column every 4 weeks during active growth.
Water depth	Saturated to 25 cm
Comments	This species can produce field-ready transplants in 8 to 10 weeks
Field Planting	
Propagule	Mature potted transplants
Season	Spring to midsummer
Substrate	Sand to muck
Depth	Moist soil to 25 cm
Comments	Highly resistant to herbivory and drought

Pickerelweed	
Species	
Scientific name	*Pontederia cordata*
Common name	Pickerelweed, pickerel plant
Growth Characteristics	
Growth form	Rhizomatous emergent forb
Reproduction	Proliferates vegetatively by producing new shoots along rhizomes; reproduces sexually by seed.
Perennation	Herbaceous perennial; overwinters as dormant rhizomes
Range	Eastern United States
Use	Valuable for fish habitat and waterfowl food
Culture	
Plant	Rhizome tips from spring to midsummer
Produce	Mature transplants
Light	75 to 100 percent full sunlight
Container	6-in. (1-gal) nursery pots
Substrate	Most soil types
Fertilization	2 g ammonium sulfate per qt of potting medium. Supplement by adding approximately 1 mg ammonium nitrogen/L to the water column every 4 weeks during active growth.
Water depth	Saturated to 50 cm
Comments	This species can produce field-ready transplants in 4 to 6 weeks. Leaves are susceptible to aphid infestation.
Field Planting	
Propagule	Mature potted transplants
Season	Early spring to midsummer
Substrate	Sand to muck
Depth	Moist soil to 50 cm
Comments	Susceptible to herbivory by waterfowl and mammals; moderately tolerant of desiccation

REPORT DOCUMENTATION PAGE

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14. ABSTRACT
Man-made reservoirs initially lack aquatic plants, and their operation for flood protection or water supply may result in extreme water level fluctuations that hinder natural establishment. In many cases natural establishment could take decades or even longer. In the interim these reservoirs provide relatively poor aquatic habitat and water quality. Unvegetated aquatic ecosystems are also at risk of invasion by problematic, nonindigenous species. These unvegetated man-made systems would benefit from establishment of native aquatic plants.

Even natural ecosystems such as lakes and ponds may have lost their aquatic flora due to chronic disturbance or long-term vegetation management. These systems also often suffer impaired water quality, are at risk of re-invasion by exotic species, and would benefit from native plant restoration.

This report describes updated techniques for production of plant propagules and their use for establishment of native plant communities in unvegetated freshwater ecosystems.

15. SUBJECT TERMS
See reverse.

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15. SUBJECT TERMS

Aquatic plant establishment
Aquatic plant management
Aquatic plant propagation
Aquatic plant restoration
Submersed aquatic plant
Submersed aquatic vegetation
SAV
Founder colony
Native aquatic plant